A Modeling Study of Flow Diversion and Focusing in Unsaturated Fractured Rocks

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RESEARCH OBJECTIVES

In a complex subsurface system with multiple layers, faults, and spatially varied alteration of rock properties, flow diversion and focusing are natural phenomena. However, quantitatively describing the magnitude and the spatial patterns of flow diversion and focusing is a challenge for both measurements and modeling. The objective of this study is to develop a systematic modeling approach, taking the Yucca Mountain unsaturated zone (UZ) as an example, to analyze and describe flow diversion and focusing in unsaturated fractured rocks, under ambient steady-state flow conditions.

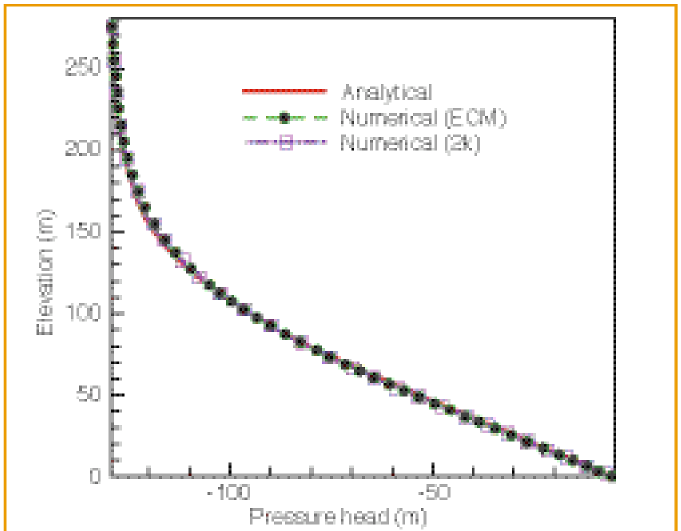

Figure 1. Comparison of pressure-head profiles in the PTn23 layer, calculated using analytical and numerical solutions

APPROACH

We first approximated the fractured tuffs of Yucca Mountain using the effective continuum model (ECM). For this, we used analytical solutions to identify the critical layers and layer interfaces in terms of flow diversion and to estimate the potential magnitudes of such diversion at typical locations. Then, we approximated the fractured tuffs as dual-permeability media and developed a large 3-D numerical grid (over one million gridblocks) to incorporate the site-specific data (including the knowledge obtained from the analytical solutions). The parallel-computing version of TOUGH2 was used to perform the numerical modeling, and the 3-D numerical modeling results were partly verified with field measurements.

ACCOMPLISHMENTS

We extended the analytical solutions of capillary barriers derived by Warrick et al. (1997) for porous media to the case of fractured media (under the ECM approximation) represented by specific geological units (and layers within those units) at Yucca Mountain. The analytical solutions show that, under present-day ambient conditions, capillary diversion occurs primarily within nonwelded units (i.e., units where matrix flow is dominant), like the Paintbrush nonwelded tuff (PTn) unit at Yucca Mountain. Among the critical rock layers within that unit, PTn21, PTn23, and vitric Calico Hills-1 (CH1) conduct the most down-dip diversionary flow, whereas PTn22, PTn24, and vitric CH2 act as capillary barriers to the downward percolation flux. Under dry, ambient conditions, the analytical solutions are good approximations of the capillary barrier system of fractured tuffs (Figure 1).

The 3-D numerical flow model developed in this study is (up to now) the most detailed site-scale model of the Yucca Mountain UZ over several decades of site study. The numerical simulations show that, although the net infiltration rate at the surface depends on various factors, including topography, soil thickness, vegetation, and rock type, the percolation flow patterns are considerably modified during transit through the thick unsaturated zone and are primarily controlled by a few critical rock layers and faults.

SIGNIFICANCE OF FINDINGS

The results show that:

1. The analysis that combines analytical solutions with large-scale numerical modeling is effective for analyzing and describing flow diversion and focusing in unsaturated rock.
2. Large-scale lateral flow could take place in the UZ at Yucca Mountain under ambient conditions. The combined effects of horizontal and vertical barriers result in generally reduced percolation flow through the proposed repository horizon, but also in flow focused downward along penetrating faults.
3. Because lateral flow occurs within a few layers and often turns into focused vertical flow via faults in the models, more detailed information about them is critical to fully understand and describe flow diversion and focusing in the UZ.

RELATED PUBLICATION

Pan, L., Y.-S. Wu, and K. Zhang, A modeling study of flow diversion and focusing in unsaturated fractured rocks. Vadose Zone Journal, 2002 (submitted); Berkeley Lab Report LBNL-49274, 2002.

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